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# P6_9 Sailing Away from Global Warming

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**Abstract**

Concern for global warming has raised over the last few decades, hence motivations to palliate its effects have increased. We investigate increasing the radius of Earth's orbit by solar sailing in order to reduce the amount of solar radiation incident on the planet, consequently reducing surface temperatures. We found that Earth's distance from the Sun would have to increase by $1.2 \times 10^9$ m and the surface area of the sails needed is approximately $1.4 \times 10^{54}$ $m^2$.

## Introduction

Global warming is a concerning issue in modern society. Most sources estimate that average global temperatures have increased by almost 1 °C since the $19^{th}$ century [1]. We investigate the change in Earth's orbital radius necessary to reduce the temperature such that it cancels the recent warming. We consider the force of radiation pressure that photons from the Sun exert on a hypothetical sail-like structure around the Earth in order to achieve this orbital shift.

## Theory

***New orbit radius -*** The power radiated by the Sun can be calculated from the Stefan - Boltzmann law:

$$P_\rho = \sigma T^4 \tag{1}$$

Where $P_\rho$ is the power density radiated; $\sigma$ is the Stefan-Boltzmann constant, $5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$; and $T$ is the temperature of the Sun, 5772 K [2]. To find the net power radiated by the Sun we multiply Eq. (1) by the surface area of the Sun, $A_s$, for which we assumed a radius of $6.9\times10^8$ m [2]. This divided by the surface area of a sphere , $A_r$, of radius $r$, is the power density of the radiation, $P_{\rho r}$, at a distance $r$ from the Sun:

$$P_{\rho r} = \frac{\sigma T^4 A_s}{A_r} \tag{2}$$

Multiplying Eq. (2) by the surface area of the Earth on which the Sun's radiation is incident, approximated as a flat circle, and accounting for the energy reflected due to the surface's albedo $a$, 0.3 [3], we find the total energy absorbed by the planet:

$$E_{in} = \frac{\sigma T^4 A_s}{A_r}(1-a)(\pi R_e^2) \tag{3}$$

To avoid a constant rising surface temperature, $T_e$, $E_{in}$ must equal $E_{out}$; the energy emitted by the Earth. If Earth is approximated as a perfect blackbody of radius $R_e$:

$$E_{out} = \sigma T_e^4 \, 4\pi R_e^2 \tag{4}$$

Equating Eq. (3) & (4) and solving for $T_e$ we obtain the following relationship:

$$T_e = \left(\frac{T^4 A_s(1-a)}{16\pi r^2}\right)^{1/4} \tag{5}$$

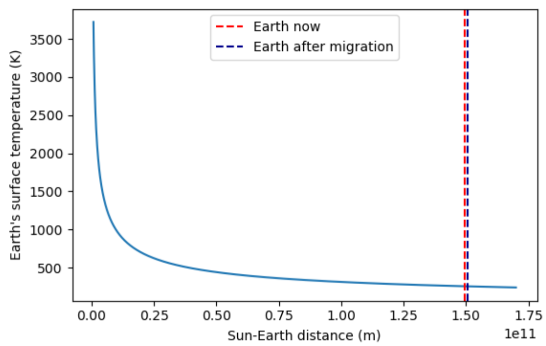


Figure 1: The dashed red line represents the Earth's current orbital radius, $1.496{\times}10^{11}$ m [3]. The dashed blue line represents the new orbital radius, $1.507\ {\times}10^{11}$ m, if temperature was to drop by 1 ℃.

Figure 1 shows $T_e$ plotted as a function of increasing $r$. The distance over which the surface temperature would drop by 1 ℃, $s$, is found to be $1.2 \times 10^9$ m.

***Sailing* -** Theoretically, we could increase Earth's orbital radius by using the radiation pressure the Sun exerts on it. By the use of sails, the surface area over which radiation is incident can be increased. For simplicity, we ignore the sails' mass and only consider Earth's ($M_e$, $5.97 \times 10^{24}$ kg [3]). To shift the planet, the work done by the solar radiation exerted on the total surface area should be equal to the gravitational potential difference between the old ($d$) and new ($d + s$) orbital radii, $1.496{\times}10^{11}$ m [3] and $1.507\ {\times}10^{11}$ m respectively:

$$\int_{d+s}^{d} -\frac{GM_sM_e}{r^2}dr = \frac{s\,A_{sys}}{c}\left[P_{\rho r}\right]_d^{d+s} \qquad (6)$$

where $G$ is the gravitational constant, $6.67 \times 10^{-11}$ m$^3$kg$^{-1}$s$^{-2}$; $M_s$ is the mass of the Sun, $2.0 \times 10^{30}$ kg [2]; $M_e$ is the mass of the Earth, previously stated; $c$ is the speed of light, $3 \times 10^8$ ms$^{-1}$; $s$ is the distance between the two orbits; and $A_{sys}$ is the area of the Earth plus the sails. The left hand side of Eq. (6) represents the gravitational potential, while the right hand side is simply Eq. (2) divided by the speed of light (which gives a pressure), timed by the area of the Earth-sail system (yielding a force), multiplied by the distance between both orbits, which result is the work to be done on the system for the planet migration. If the surface is perfectly reflective, the momentum change experienced by both the reflected photons and the object they are incident on increases by a factor of 2. Therefore, assuming the sails are perfectly reflective, and that the Earth absorbs 70 % and reflects the other 30 % [3], rearranging Eq. (6) gives an expression for $A_{sys}$ (Eq. (7)), which yields an area of $1.4\ {\times}10^{54}$ m$^2$.

$$A_{sys} = \pi(2R_t^2 - 0.7R_e^2) = 1.4 \times 10^{54}\ \ \mathrm{m}^2 \qquad (7)$$

Further rearranging of Eq. (7) to find $R_t$, the total radius of the Earth with the surrounding sails, results in Eq. (8) and a consequent radius of $4.7\ {\times}10^{26}$ m.

$$R_t = \left(\frac{A_{sys}}{2\pi} + \frac{0.7R_e^2}{2}\right)^{1/2} = 4.7 \times 10^{26}\ \ \mathrm{m} \qquad (8)$$

## Conclusion

From the results obtained we concluded that moving the Earth away from the Sun by only using solar radiation pressure is highly unrealistic. The radius of the sails is outlandishly large, even greater than Earth's orbital radius. Furthermore, the sail dimensions found are yet an underestimation of the real value, as such structure was assumed of negligible mass. Therefore, solar sailing has been shown not to be a viable, nor a realistic solution for global warming and alternative palliative methods should be considered.

## References


[1] `https://climate.nasa.gov/vital-signs/global-temperature/` [Accessed 18 October 2018]

[2] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html` [Accessed 18 October 2018]

[3] `https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html` [Accessed 18 October 2018]